Mahidol University *Wisdom of the Land*

Chapter 2

Digital Image Fundamentals

Topics

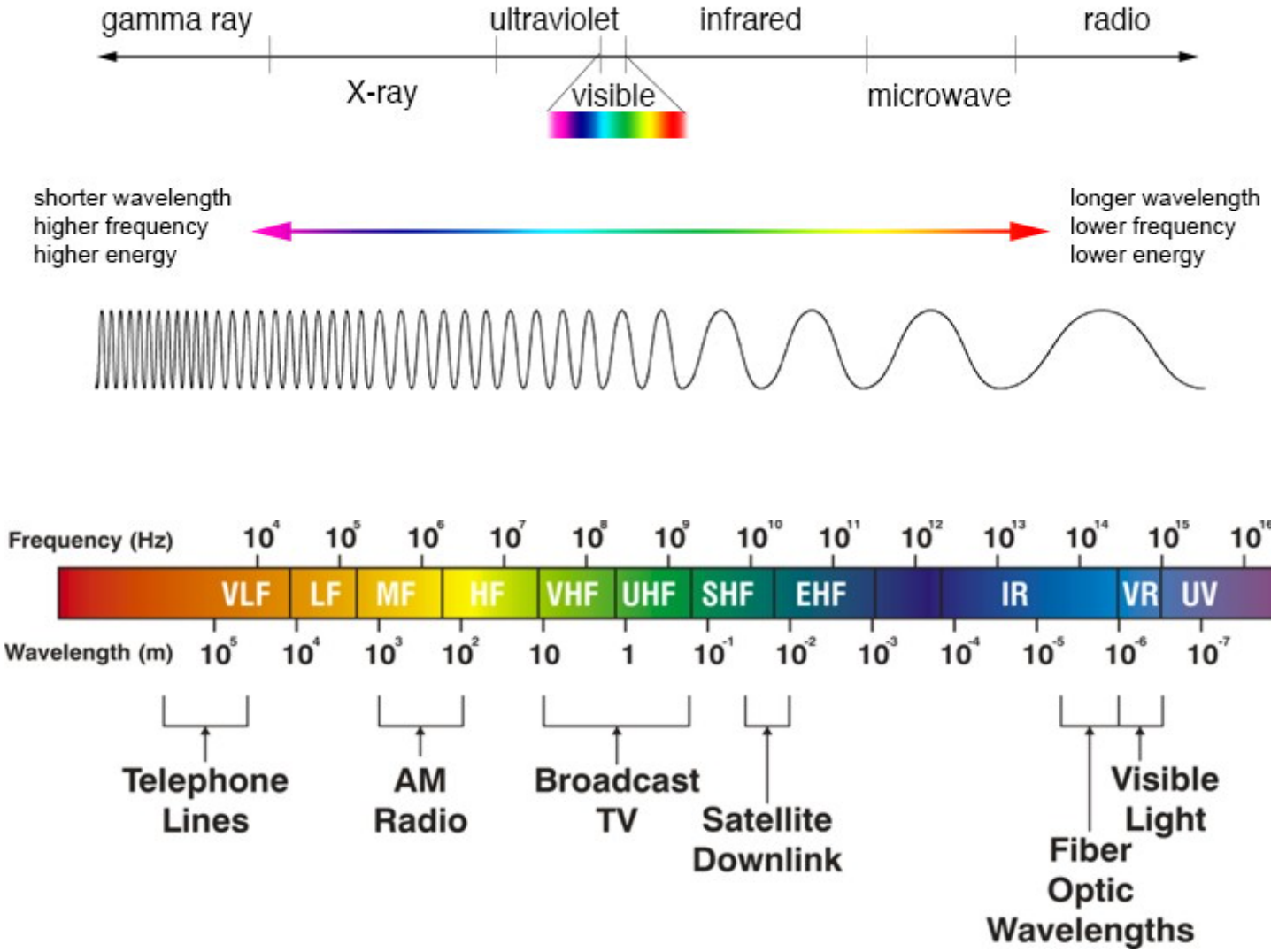
- Electromagnetic spectrum
- Image sensing and acquisition
- Image sampling and quantization

Sources of Digital Images

- The principal source for the images is the electromagnetic (EM) energy spectrum.

- The spectral bands are grouped according to energy per photon ranging form the gamma rays (highest energy) to the radio waves (lowest energy).

Electromagnetic Spectrum

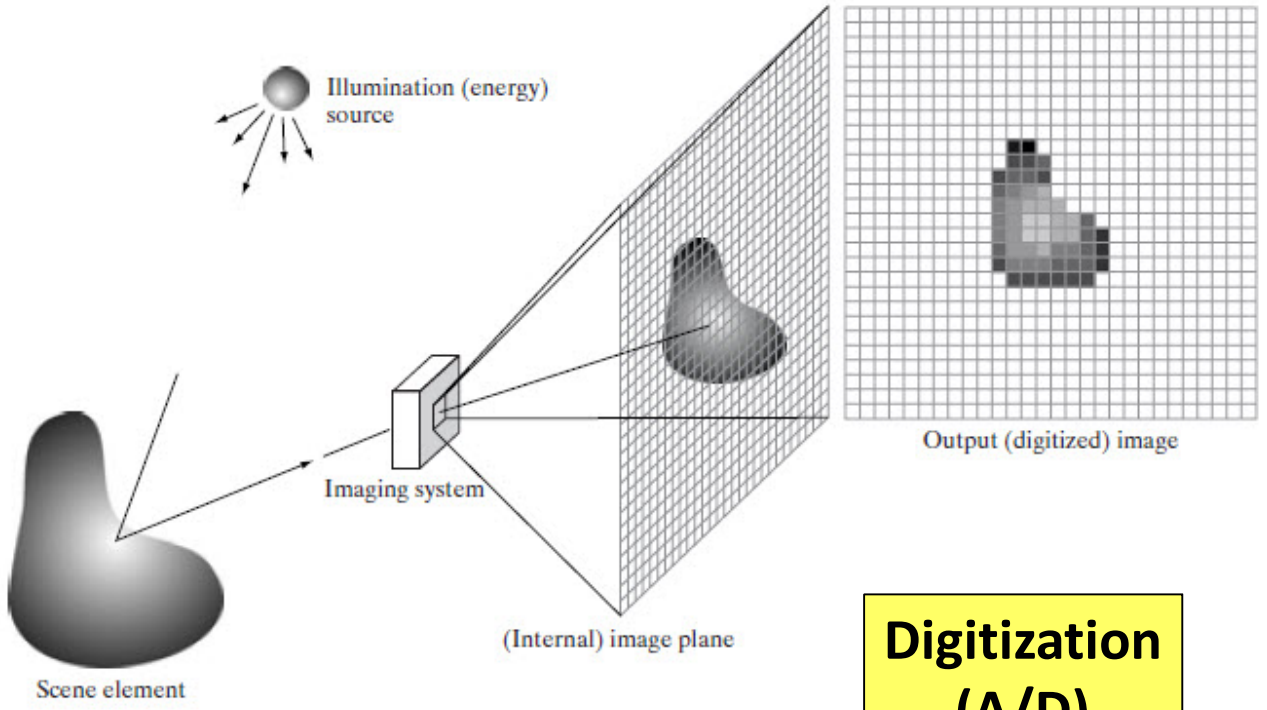


Topics

- Electromagnetic spectrum
- Image sensing and acquisition
- Image sampling and quantization

Image Sensing and Acquisition

Energy source → **Sensor** → **Analog image** → **Digitization (A/D)** → **Digital image**

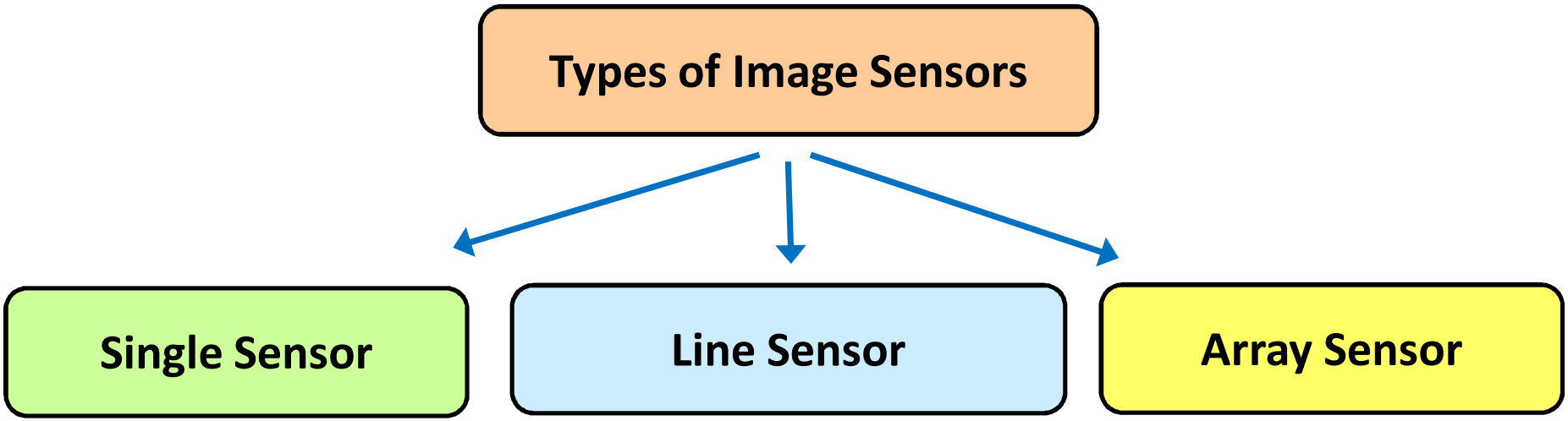


Digitization (A/D)

Sampling → **Quantization**

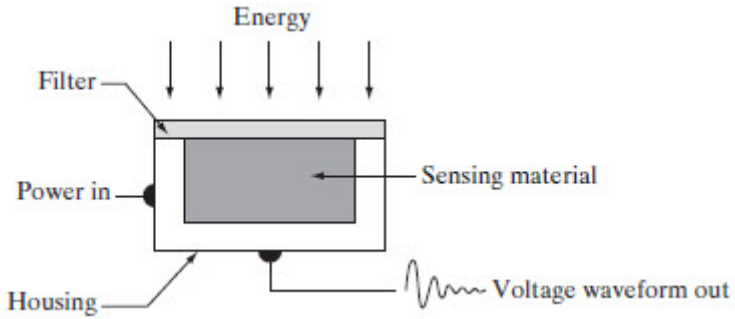
Image Sensors

- Imaging sensors are used to transform the illumination energy into digital images.

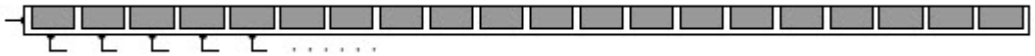


Types of Image Sensors

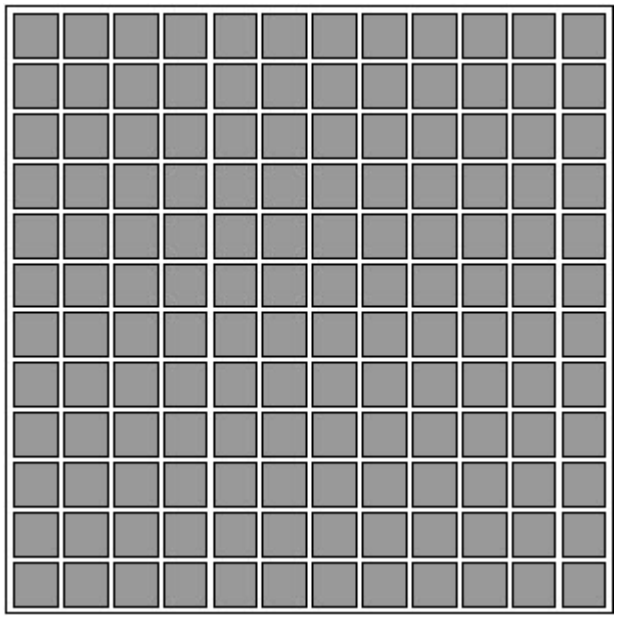
Single Sensor



Line Sensor



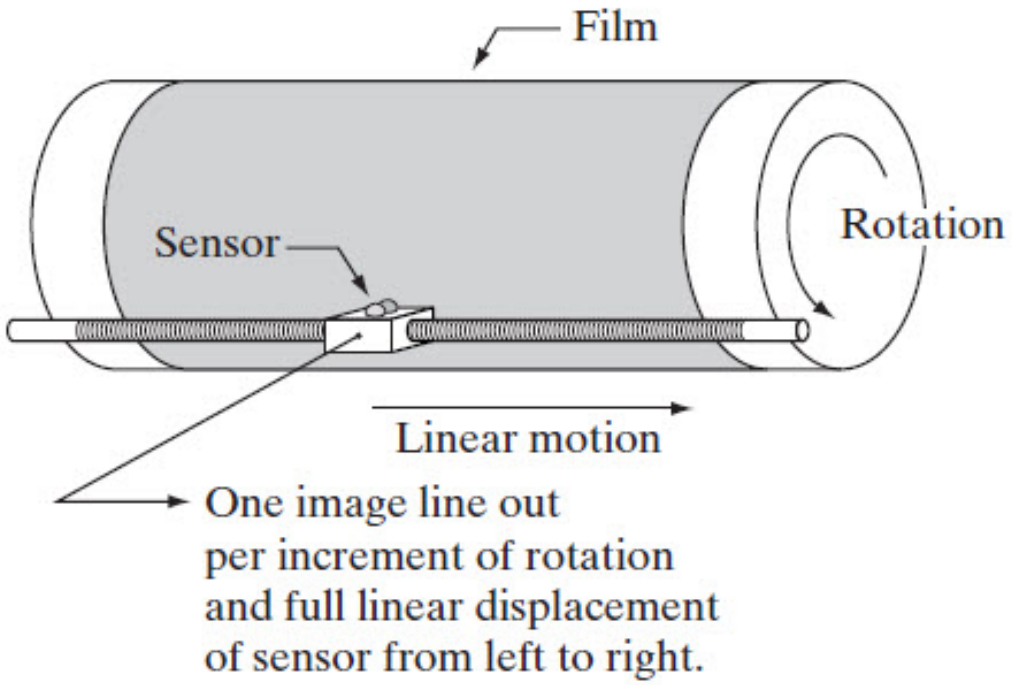
Array Sensor



A digital quantity is obtained from each sensor by digitizing its response voltage.

Single Sensor

- **Image acquisition using single sensor**

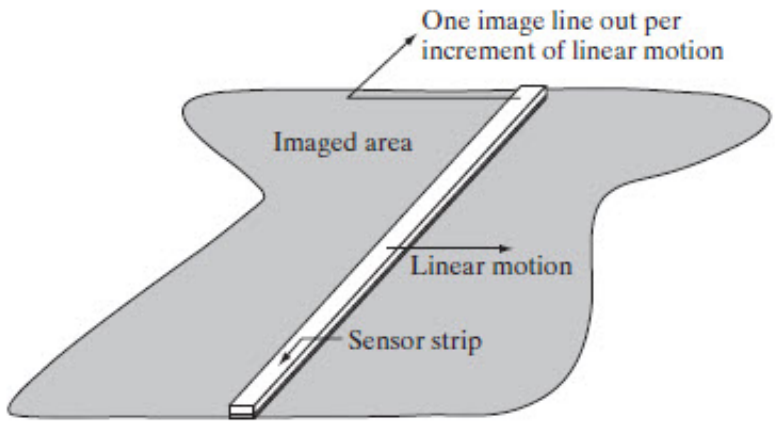


Combining a single sensor with motion to generate a 2-D image.

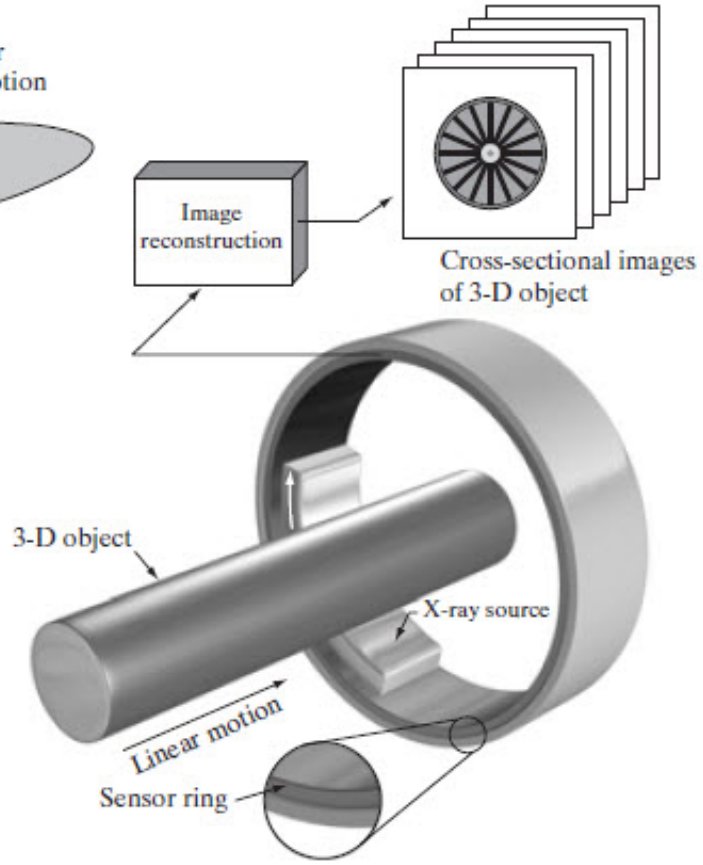
Example : Single Sensor

Line Sensor

- **Image acquisition using a line sensor**

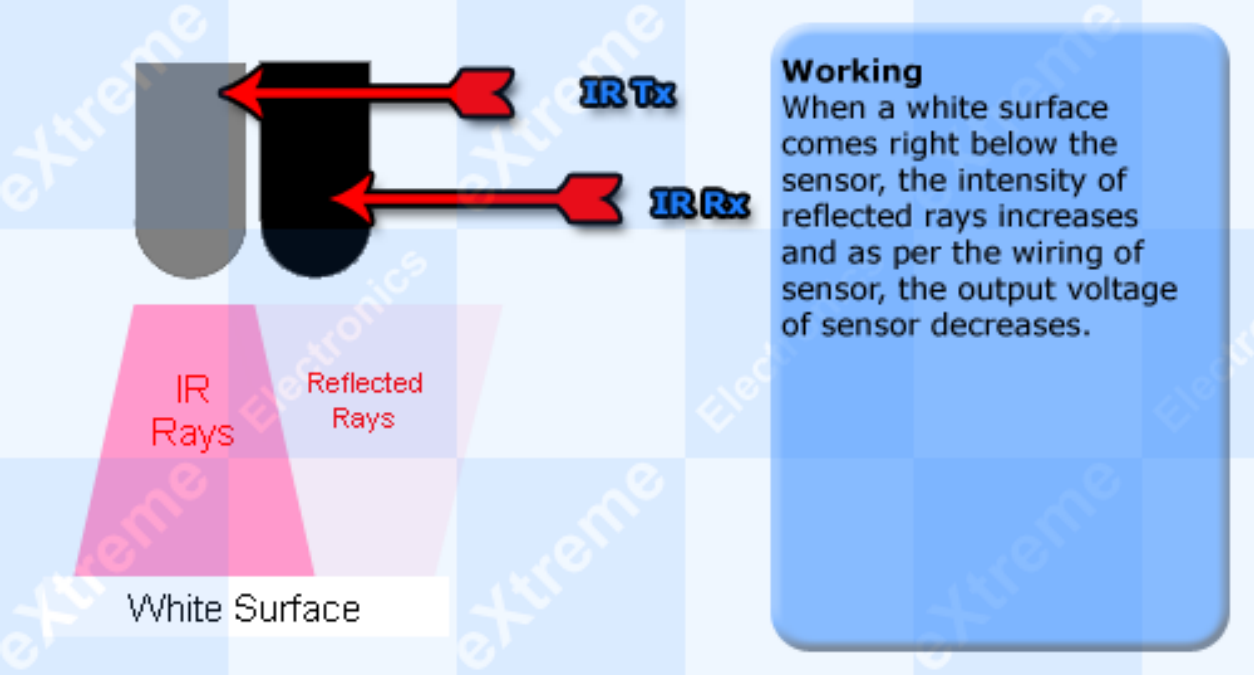


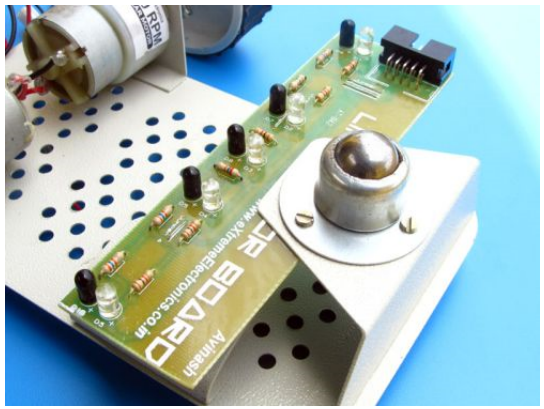
(a) Linear sensor strip



(b) Circular sensor strip

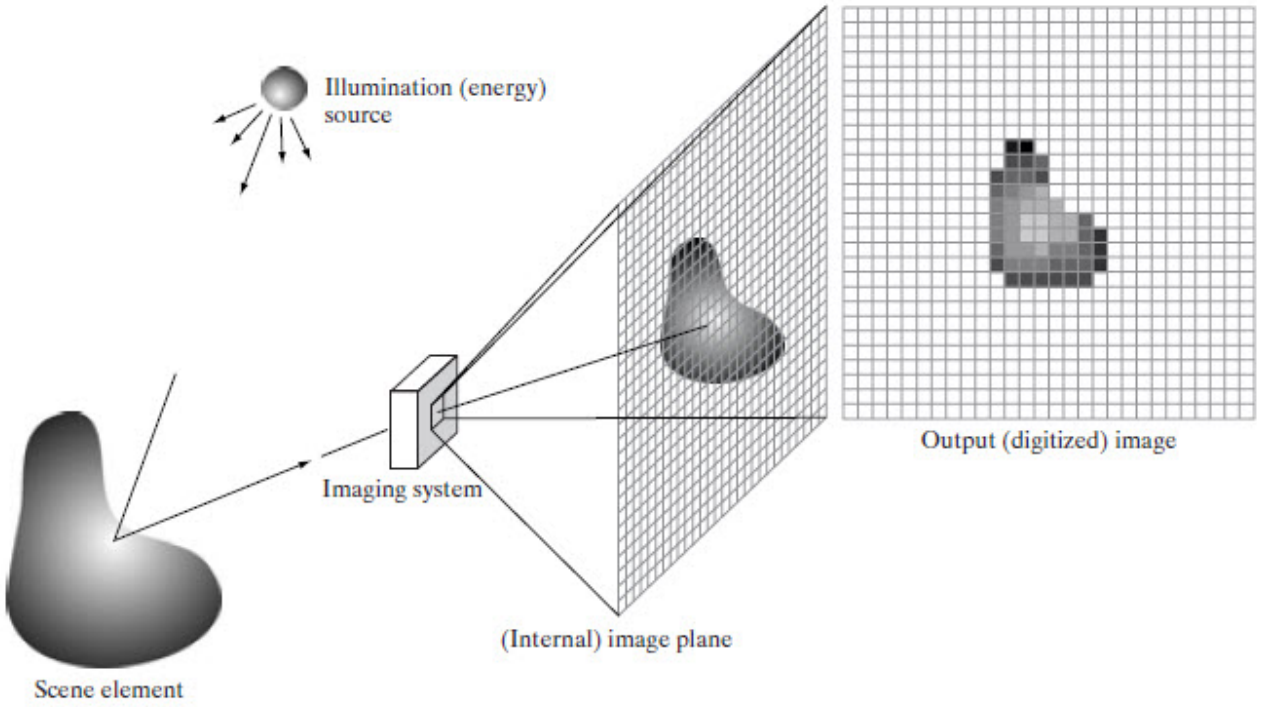
Example : Line Sensor





Array Sensor

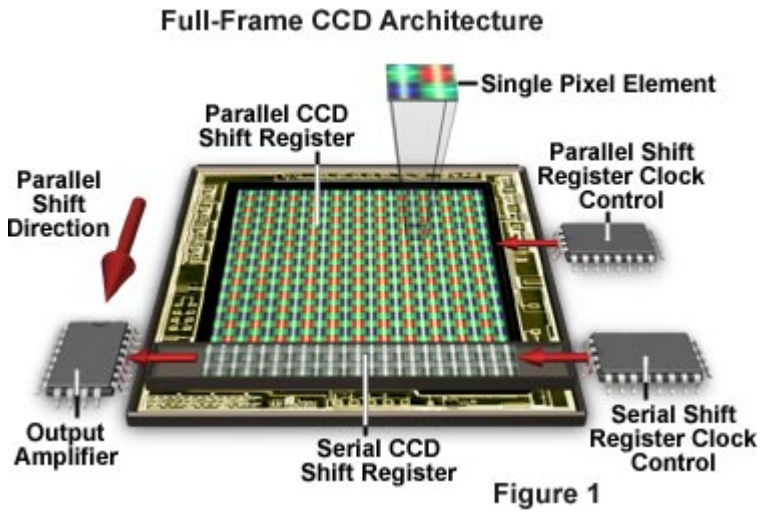
- **Image acquisition using an array sensor**

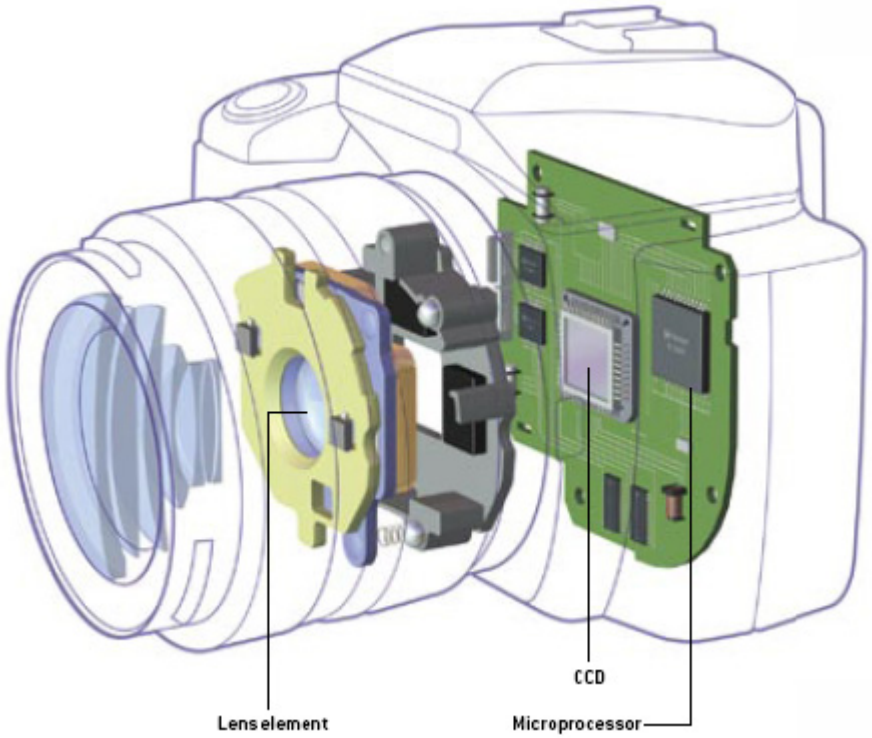


An example of the digital image acquisition process.

- a) Energy ("illumination") source.
- b) An element of a scene.
- c) Imaging system.
- d) Projection of the scene onto the image plane.

Example : Array Sensor





charge-coupled devices (CCDs)

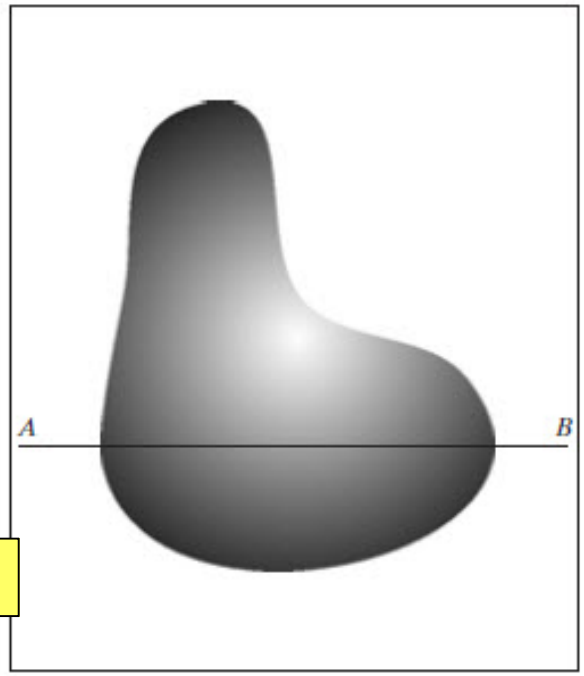
Topics

- Electromagnetic spectrum
- Image sensing and acquisition
- Image sampling and quantization

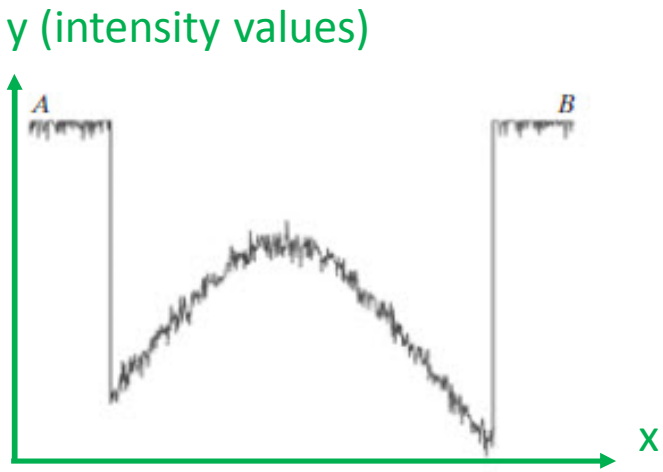
Image Sampling and Quantization

- A digital image can be obtained by converting an analog image (continuous interval) in a digital form (discrete interval) using :
  - Sampling
  - Quantization
- Given an analog image, *f(x,y)*,
  - digitizing the coordinate values is called sampling.
  - digitizing the amplitude (intensity) values is called quantization.

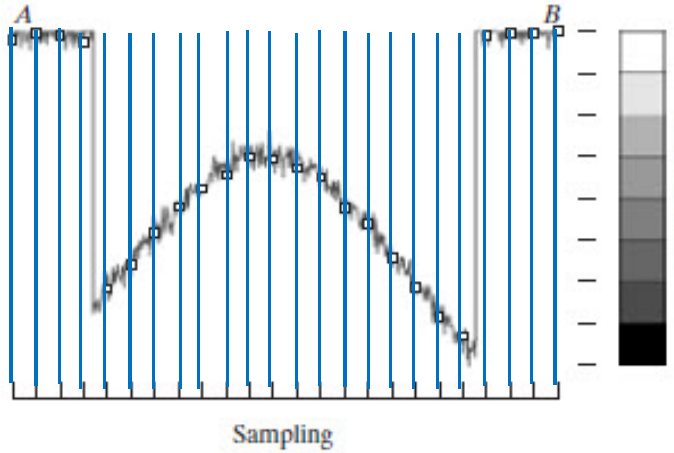
Basic Concepts in Sampling and Quantization



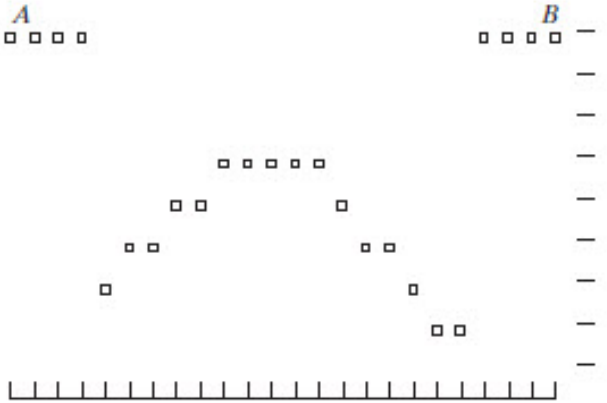
Analog image



A scan line from A to B in the analog image



Sampling

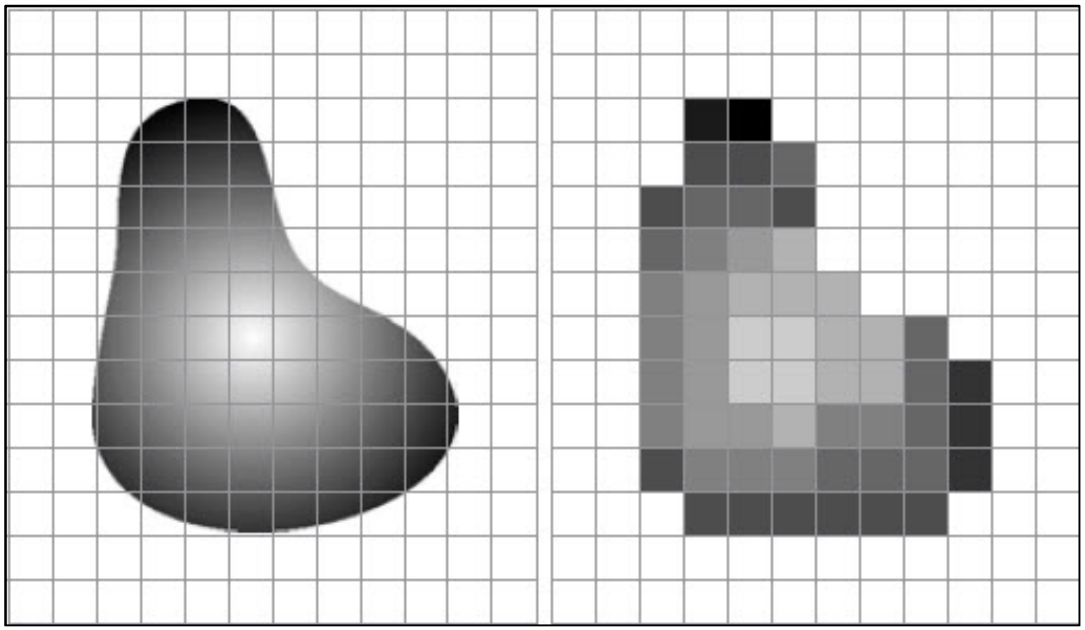


Quantization

Image Sampling and Quantization

- Sampling: digitizing the two-dimensional spatial coordinate values
- Quantization: digitizing the amplitude values (brightness level)

Continuous image projected onto a sensor array



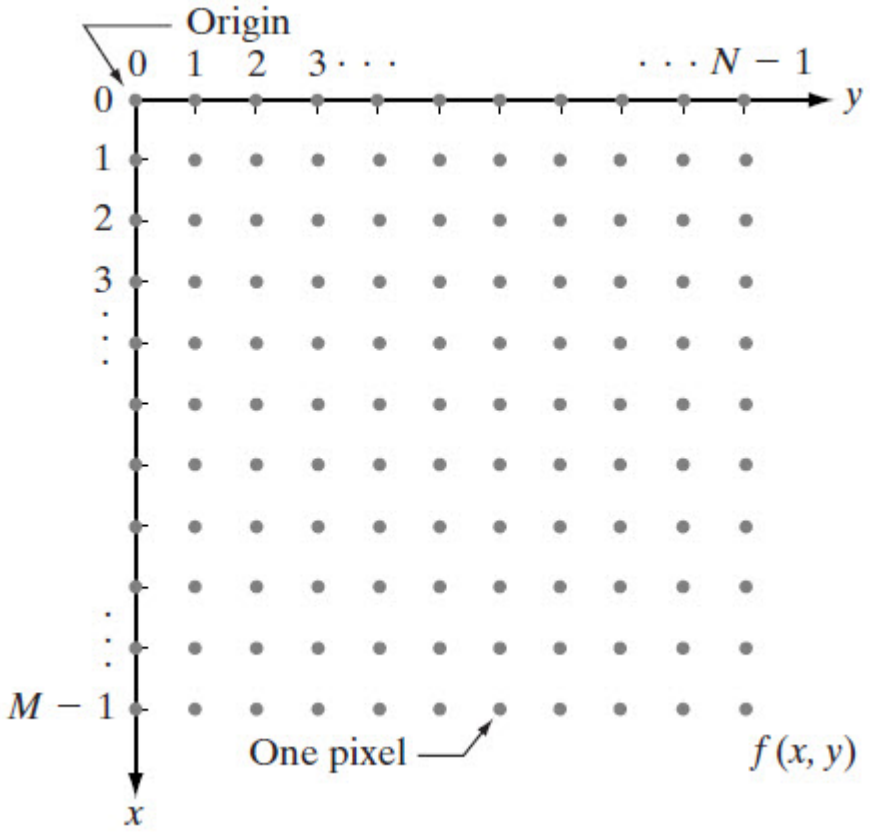
Result of image sampling and quantization

Representing Digital Images

- A matrix representing an *M x N* image.
- *M* and *N* can be any positive integers.
- The number of gray levels, *L*, is an integer power of 2.

  $L = 2^k$ (k is bits per pixel)
- The gray levels are integers in the interval [0,*L*-1].
- Number of bits, *b*, required to store a digitized image:

  $b = M \times N \times k$



Representing Digital Images

- The number of bits required to store a digitized image:

$$b = M \times N \times k$$

- Assume that $M=N$

$$b = N^2 \times k$$

N/k	1 ($L = 2$)	2 ($L = 4$)	3 ($L = 8$)	4 ($L = 16$)	5 ($L = 32$)	6 ($L = 64$)	7 ($L = 128$)	8 ($L = 256$)
32	1,024	2,048	3,072	4,096	5,120	6,144	7,168	8,192
64	4,096	8,192	12,288	16,384	20,480	24,576	28,672	32,768
128	16,384	32,768	49,152	65,536	81,920	98,304	114,688	131,072
256	65,536	131,072	196,608	262,144	327,680	393,216	458,752	524,288
512	262,144	524,288	786,432	1,048,576	1,310,720	1,572,864	1,835,008	2,097,152
1024	1,048,576	2,097,152	3,145,728	4,194,304	5,242,880	6,291,456	7,340,032	8,388,608
2048	4,194,304	8,388,608	12,582,912	16,777,216	20,971,520	25,165,824	29,369,128	33,554,432
4096	16,777,216	33,554,432	50,331,648	67,108,864	83,886,080	100,663,296	117,440,512	134,217,728
8192	67,108,864	134,217,728	201,326,592	268,435,456	335,544,320	402,653,184	469,762,048	536,870,912

Example : Representing Digital Images

- **For an 8-bit image of size 256 x 256, determine its grayscale and storage size.**

- **Solution:**
  - k=8, M=N=256
  - Number of gray levels (L):

$$L = 2^k$$
$$= 2^8$$
$$= 256$$

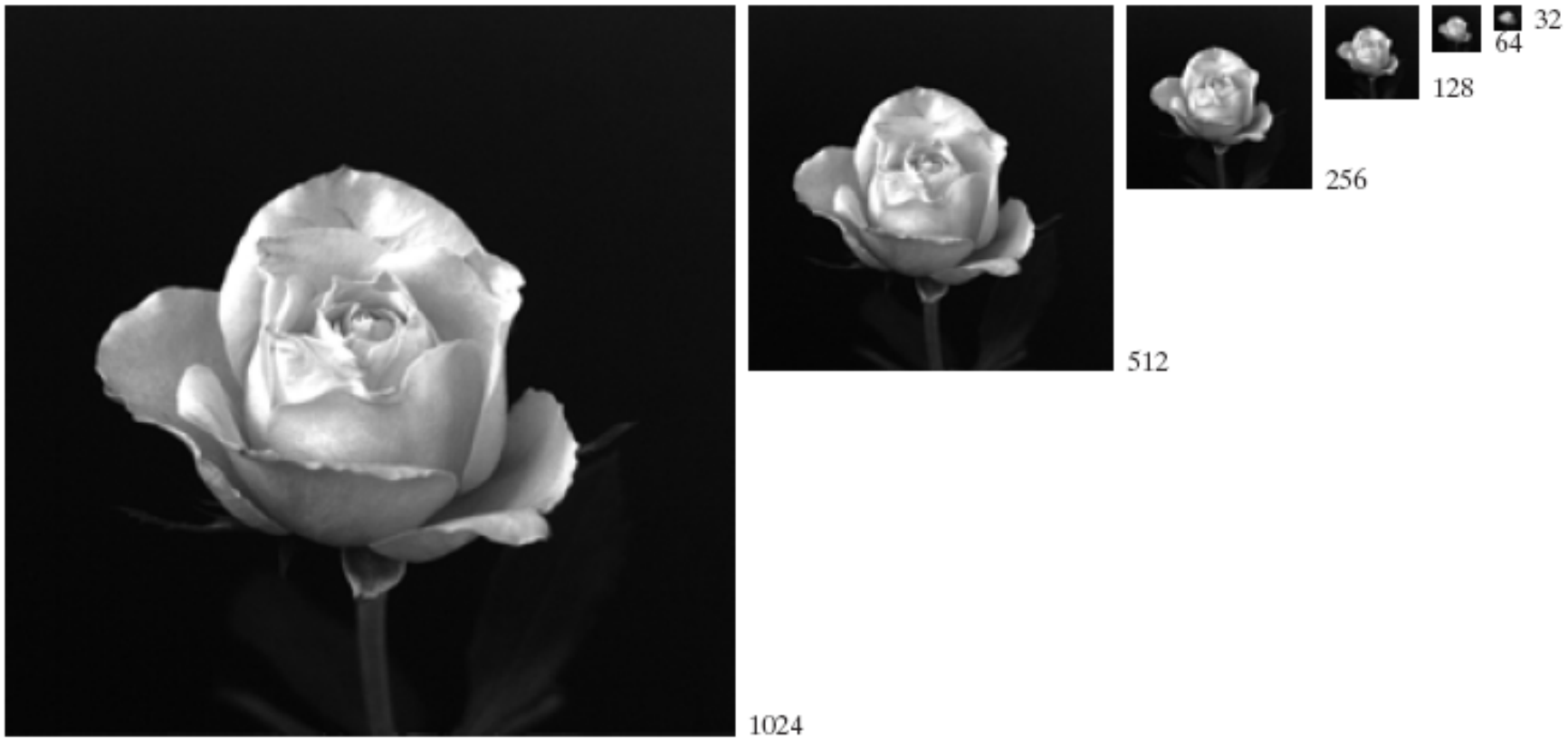
The grayscale range is 0 to 255.

  - Storage size (b):

$$b = M \times N \times k$$
$$= 256 \times 256 \times 8$$
$$= 524{,}288 \text{ bits}$$

Sampling and Spatial Resolution

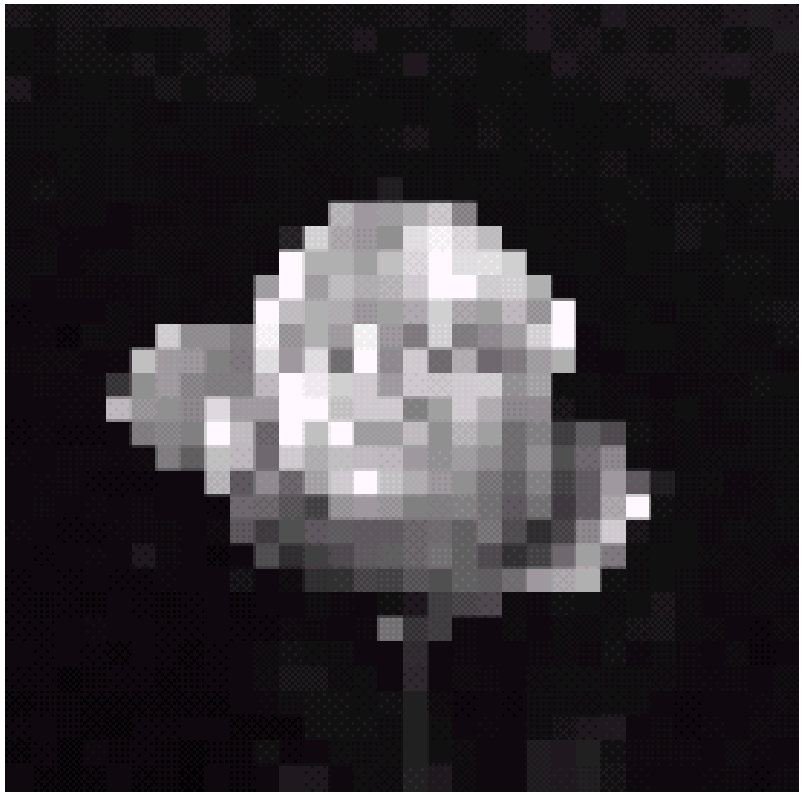
- Sampling is the principal factor determining the spatial resolution of an image.
- Sampling determines the number of pixels of a digitized image.



Effect of Reducing the Spatial Resolution

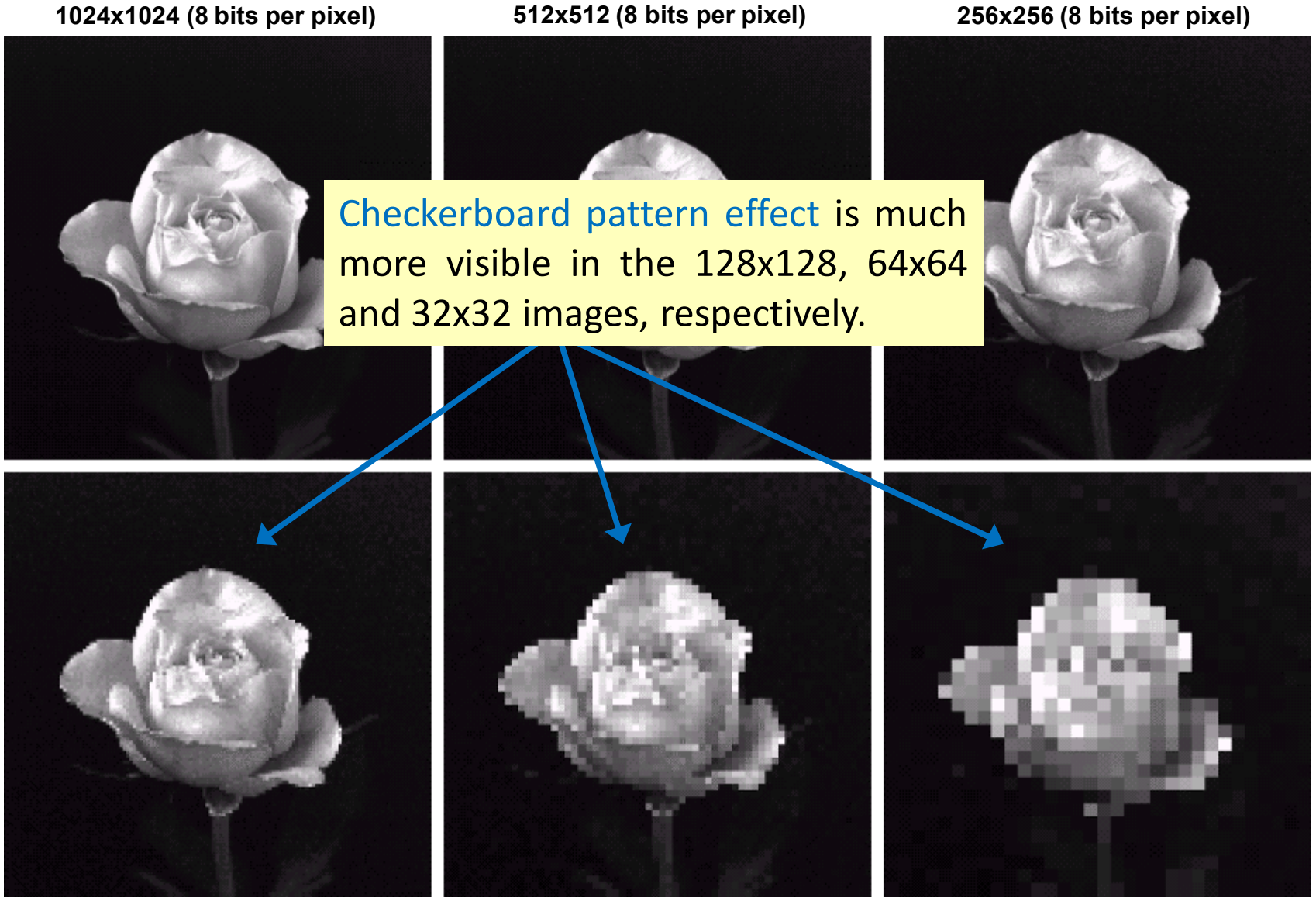
- Decreasing the spatial resolution of a digital image, within the same area, may result in what is known as checkerboard pattern. Image details are lost when the resolution is reduced.

1024x1024 (8 bits per pixel)



32x32 (8 bits per pixel)

Effect of Reducing the Spatial Resolution



Exercise

- Write a program to demonstrate the checkerboard pattern effect, using moon dark image as input image.

Quantization and Gray-Level Resolution

- Quantization is the most important factor determining the gray-level resolution of an image.
- Quantization determines the number of gray levels that each pixel can take.
- The number of gray levels is usually given in terms of the number of bits.

Number of Bits	Number of Gray-Level	Examples
1	2	0, 1
2	4	00, 01, 10, 11
4	16	0000, 0101, 1111
8	256	00110011, 01010101
16	65,536	1010101010101010

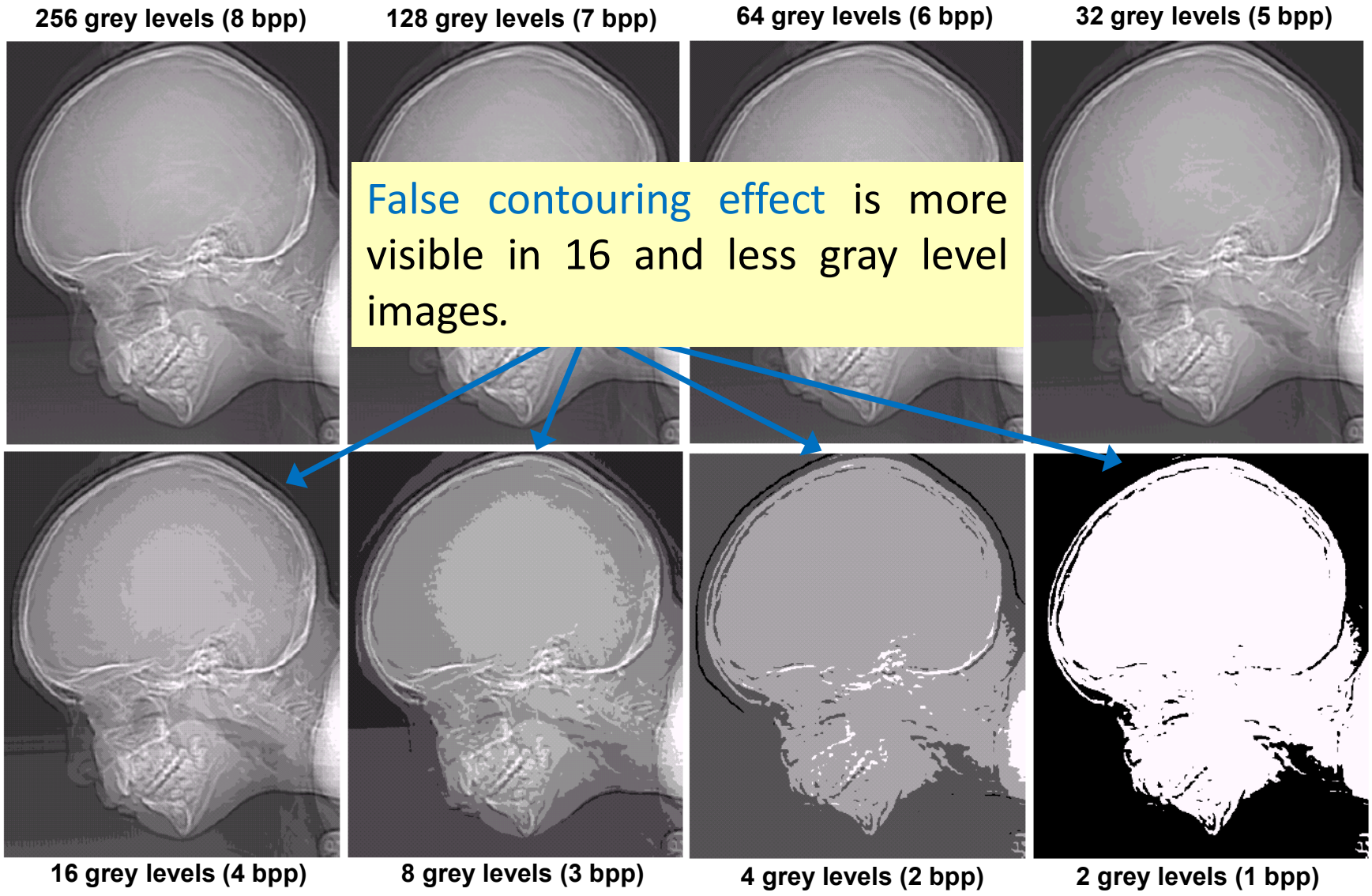
Effect of Reducing the Spatial Resolution

- Decreasing the gray-level resolution of a digital image may result in what is known as false contouring. The effect is caused by the use of an insufficient number of gray levels in smooth areas of a digital image.

256 grey levels (8 bits per pixel)

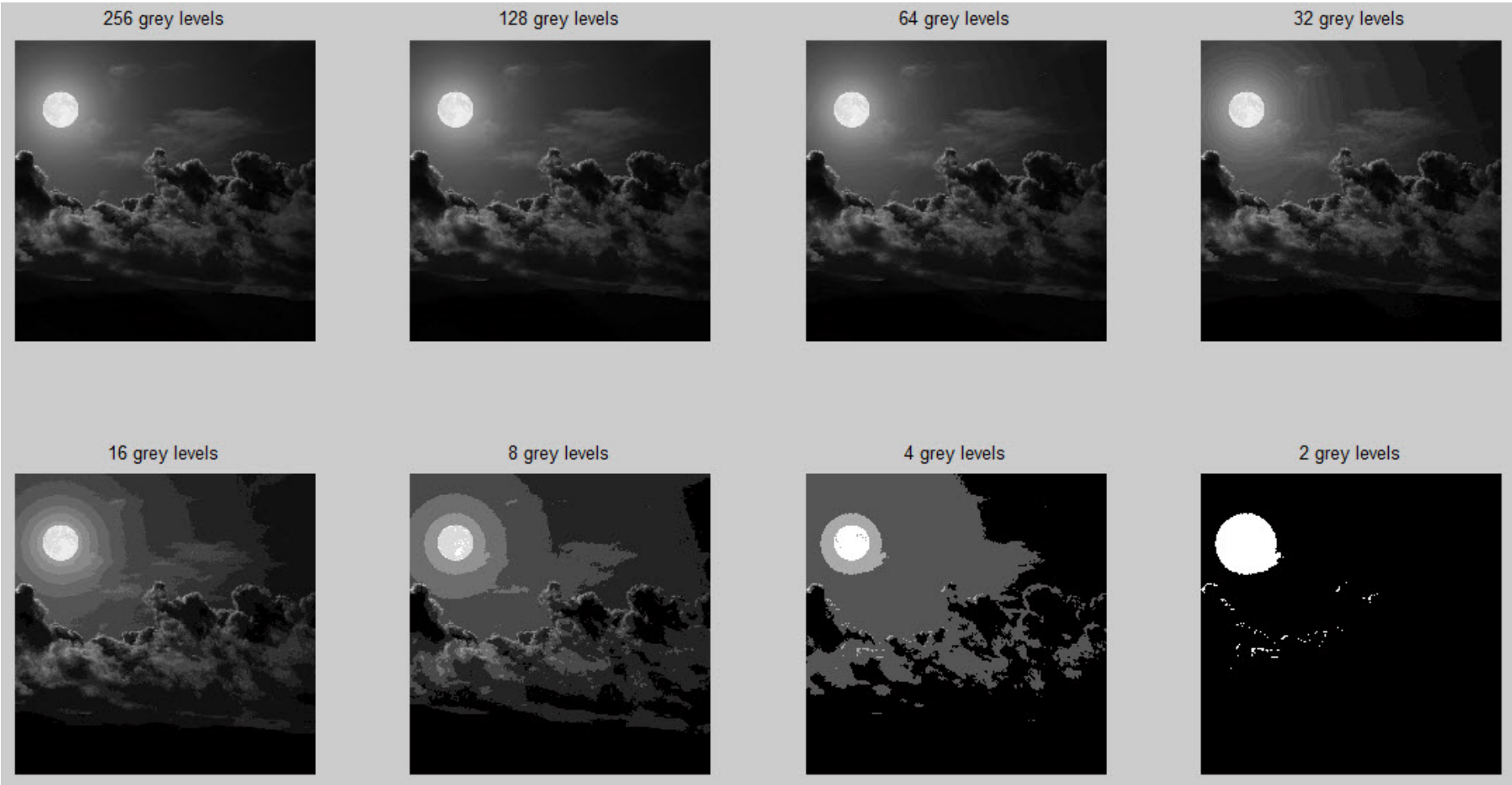
2 grey levels (8 bits per pixel)

Effect of Reducing the Gray-Level Resolution



Exercise

- Write a program to demonstrate the false contouring effect, using "moon_dark.bmp" as input image.



How Many Gray-Levels are Required?

- Contouring is most visible for a ramp

32 gray levels

64 gray levels

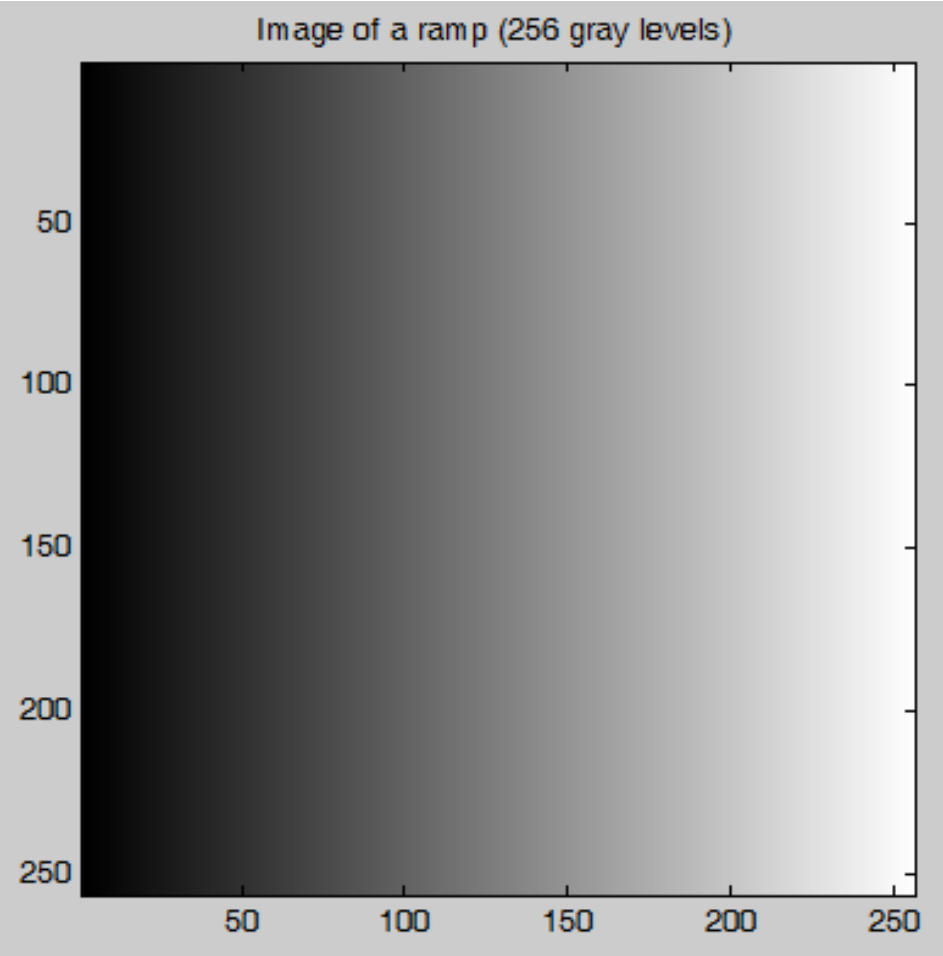
128 gray levels

256 gray levels

- The digital images are commonly quantized to 256 gray levels.

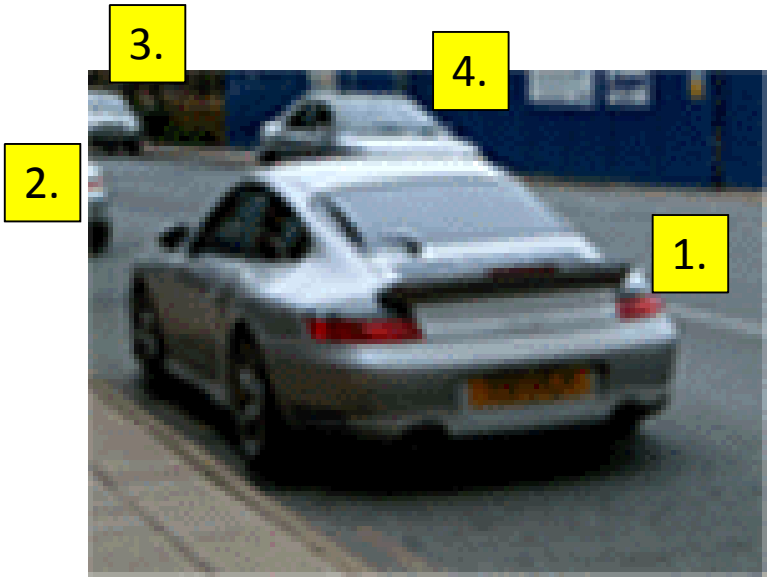
Exercise

- Write a program to create an image of a ramp, whose size is 256x256, having 256 different gray levels.



How Much is Enough?

- This all depends on what is in the image and what you would like to do with it



- The figure is good for counting the number of cars, but not for reading the number plate.

- This figure is fine for counting the number of cars and reading the number plate.

Summary

- Spatial resolution is the smallest discernible detail in an image.
- Gray-level resolution refers to the smallest discernible change in gray level.

Thanks for your attention